NSLS Accelerator Division

James B. Murphy
ASSOCIATE CHAIR FOR ACCELERATORS

Organization and Mission

The NSLS Accelerator Division (AD), headed by James B. Murphy, is organized into two sections: the Linear Accelerator (Linac) Section, headed by Xijie Wang, and the Storage Ring & Insertion Device Section (SR&ID), headed by Boris Podobedov. The AD staff consists of eleven accelerator physicists, two engineers, three technicians, and two postdocs.

The NSLS Accelerator Division has a four-part mission:

- To ensure the quality of the electron beam in the existing NSLS booster, linear accelerator, and x-ray & vacuum ultraviolet (VUV) storage rings
- To participate in the NSLS-II project, in particular the design of the storage ring and injection system
- To operate the Magnet Measurement Lab (MML) and the Deep Ultra Violet Free Electron Laser (DUV-FEL) Laboratory
- To perform fundamental research and development (R&D) in accelerator and free-electron laser physics

2004 Activities

Injection System & Storage Ring Improvements

In 2004, the activity with the most direct benefit to the NSLS user community was the restoration of the x-ray ring lattice symmetry, which resulted in a reduction of the horizontal emittance (**Figure 1**) and a more robust operational lattice.

The basic eight-fold symmetry of the x-ray ring magnet lattice can be broken due to gradient errors in the ring quadrupoles and changes in the reference closed orbit. The quadrupole errors can be partially mitigated by the installed trim coils available in the x-ray ring for one of the quad families. In studies that took place over the summer and fall of 2004, these gradient errors were determined through a series of orbit-response matrix measurements and an elaborate analysis that included fitting a ring model to a suitable set of parameters. The mathematical model was later confirmed by a direct measurement of the dispersion function of the eight-fold symmetric lattice. The optics system was commissioned before the winter shutdown and is now in routine operation.

Another important activity regarding the storage rings was the implementation of the so-called "middle layer" software interface on the NSLS control system. The middle layer was originally developed at the Advanced Light Source (ALS) to interface between the EPICS control system and the high-level MATLAB-based accelerator physics applications. It is currently used at a number of operating and future light sources, such as SPEAR-3, the Canadian Light Source, SOLEIL, and DIAMOND. The NSLS uses a real-time control system that is different from EPICS. However, due to the clever layered client-server architecture of the NSLS control system, the SR&ID staff, together with Operations and Engineering Division (OED) staff, were able to adapt the middle layer so that it could "hook into" the NSLS control system. This allowed us to port about five man-years worth of high-level accelerator physics and control tools development to the NSLS control system. One of the tools, a MATLAB-based version of the LOCO program, was used for the x-ray ring lattice symmetry restoration.

To ensure the smooth operation of the NSLS injection system, we performed a thorough review of its operational principles and hardware systems. Aging electron and photon beam instrumentation was refurbished and new synchrotron-light monitors were added. This focused effort has led to a significant increase in the reliability of the injection system. An industrial partner was also identified to rejuvenate old klystrons for the linac injector.

A number of important contributions to the present facility came through the efforts of the magnet-measurement lab (MML) staff with support for the O&ED personnel. A vertical beam scraper assembly, built in the MML in 2003, was installed in the X13 straight section of the x-ray ring during the winter 2003/04 shutdown. Controls for the device were installed and calibrated during the May 2004 shutdown. The measurements of beam losses versus scraper position allow one to better understand the x-ray ring beam dynamics. In particular, it is possible to validate the minimum allowed vertical aperture, and hence the minimum magnetic gap, of future insertion devices planned for the x-ray ring, such as the X25 mini-gap undulator (MGU).

The magnetic design of the one-meter-long X25 MGU was finalized in 2004. The hybrid-permanent magnet design uses the newest high-field, high-temperature-capable magnets developed for hybrid/electric vehicle motors. The design is based on room temperature operation, but includes the option of cooling the magnet arrays to as low as -120° C to gain an additional 13% in field strength and a wider tuning range. Specifications for magnets and poles were developed, bids were received from three vendors, and NEOMAX America Inc. was selected. The mechanical support structure and vacuum chamber specifications were also developed and bids for construction were received from several U.S. and foreign vendors. The contract was awarded to Advanced Design Consultants Inc. A preliminary design review was held in December 2004. Delivery of the magnets, poles, and the mechanical structure are scheduled for summer 2005 and installation in the x-ray ring is planned for the winter 2005 shutdown.

It should be mentioned that the X29 MGU (designed and installed by the MML staff in collaboration with the O&E Division) and its new protein crystallography beamline were successfully commissioned in 2004 by NSLS user science and biology staff members. Optical measurements proved the X29 MGU to be performing "brilliantly" and this is currently the brightest insertion device in the NSLS complex.

NSLS-II Design Work

The NSLS-II storage ring will provide unprecedented high brightness to the NSLS user community. As such, the NSLS-II design presents challenges in the areas of lattice design, collective effects, superconducting insertion devices, and choice of injector.

Lattice: In Spring 2004 the NSLS-II lattice design team hosted visitors from the ALS, DIAMOND, the European Synchrotron Radiation Facility, KEK, and the Swiss Light Source, with the purpose of acquiring input from world-renowned experts on light source design. In the following summer, intensive effort was placed on developing improved lattice and tracking tools for addressing the higher-order nonlinear effects in the high-performance lattice. Work is continuing to optimize the baseline 24-cell triple-bend achromat lattice and we are considering the merits of other candidate lattices.

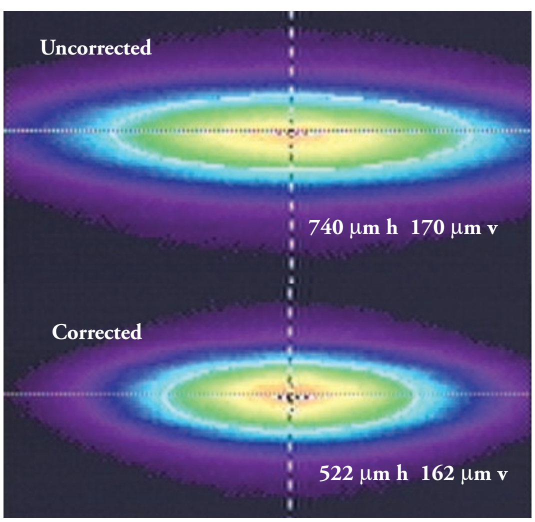

Figure 1. The x-ray ring photon beam spot size before and after the correction of the lattice symmetry.

Collective Effects: The combination of very low emittance (~ 1.5 nm), medium energy (3 GeV), and high single-bunch charge (I ~ 1 ma) makes the NSLS-II design challenging from the point of view of collective effects. To properly assess the impact of collective effects, an impedance budget is being developed, starting with the most critical components, such as MGUs, radio-frequency (RF) cavities, and beam position monitors. Much progress has been made in analyzing the impedance of vacuum chambers for the superconducting insertion devices, in particular the taper sections from the main ring vacuum chamber to the small-gap insertion devices.

Thresholds of various instabilities have been found and analyzed. In particular, the transverse mode coupling instability (TMCI) threshold driven by the resistive chamber of MGUs was estimated by comparing the resistive wall tune shift to the synchrotron tune, and confirming the estimate with computer simulations. Other important findings were related to the beam-induced heat in the mini-gap undulators, which provided concrete estimates for the cryo-designers. It was also found that employing a third-harmonic RF system will lessen the problems associated with collective effects and significantly improve the beam lifetime.

Superconducting Undulator Development: Compared to conventional permanent-magnet MGUs, superconducting undulators (SCUs) can provide higher brightness and continuous photon coverage. However, one of the most significant challenges to building an SCU for NSLS-II is the ability to measure and correct the undulator field errors. Other challenges are heat management and removal. To address these challenges head-on, we are constructing a state-of-the-art cryogenic vertical test facility (VTF) for taking magnetic and calorimetric measurements of SCU test models (**Figure 2**). The VTF will allow precise magnetic field mapping of short SCU models up to 0.4 m long, using a motorized Hall probe field mapper. The mapper, which includes an NSLS-built six-element cryogenic Hall probe, has fast on-the-fly field mapping capabilities and has been bench-tested on an existing permanent magnet undulator. A superconducting Helmholz coil is under construction to provide an in-situ calibration check of the Hall sensors in liquid helium. A pulsed-wire insert, interchangeable with the Hall probe mapper, is also under construction, to provide a complementary magnetic measurement technique. Initial bench tests of the pulsed wire insert have been successfully completed. A cryogenic safety review of the VTF is planned for January 2005. The VTF will then be installed and commissioned at the BNL Superconducting Magnet Division's facilities in 2005.

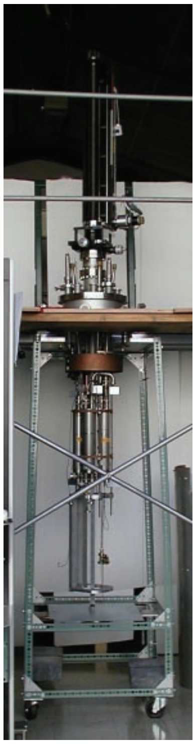

Figure 2. VTF

Both a booster synchrotron and full-energy linear accelerator were explored as possible injectors for the NSLS-II project.

The Deep Ultra Violet Free Electron Laser (DUV-FEL) Laboratory

The DUV-FEL is a dedicated platform for single-pass high-gain FEL R&D and applications. After successfully lasing at 266 nm with 800 nm laser seeding in late October 2002, experiments were carried out at the DUV-FEL last year to further explore laser-seeded high-gain harmonic generation (HGHG) FEL and improve its tunability. We also continued to provide significant support for users to explore the potential of the DUV-FEL for chemical science applications.

The chirped pulse amplification (CPA) experiments made significant progress in the last year with the development of a VUV SPIDER diagnostic apparatus and a pulse compressor. We demonstrated that by imposing a chirp on both the electron bean energy and the seed laser wavelength, a linear chirp could be detected on the HGHG FEL output. These results demonstrate the potential to generate short pulses through CPA. Another major achievement at the DUV-FEL was the successful characterization of half-cycle coherent THz pulses using an electro-optical technique.

The electron beam energy upgrade project was successfully completed with support from NSLS Engineering and Environment, Safety, and Health divisions in the last year. The DUV-FEL linac energy was upgraded from 200 to 300 MeV to enable the HGHG FEL to produce 100 µJ pulses of 100-nm light. This will establish the DUV-FEL as a premier source of ultraviolet radiation and will enable state-of-the-art gas phase photochemistry research. Furthermore, the upgraded facility will also enable future critical R&D experiments, such as multi-stage cascaded HGHG FELs and higher-harmonic HGHG ($n > 5$). The MML continued to support the DUV-FEL program in 2004 by rebuilding and recalibrating the modulator wiggler and adding a new dispersion magnet.